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A COMPREHENSIVE SUPPLY CHAIN PERFORMANCE MEASUREMENT AND EVALUATION (CSPME) METHODOLOGY

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ABSTRACT

Supply chain management (SCM) has gained a tremendous amount of attention by both practitioners and academics since the last two decades. Supply chain performance measurement (SCPM) plays a vital role for set-up the concrete strategy and a driving force for improvement in organizational productivity. An important component in supply chain design and analysis is the establishment of an appropriate performance measurement and evaluation system. The purpose of such performance measurement system is to monitor and control the supply chain performance. Also, the selection of factors or different variables affecting performance of any organization is an important or vital step in developing a performance measurement system. In this paper, a comprehensive supply chain performance measurement and evaluation (CSCPME) methodology has been developed. The critical performance measures reflect the five specific criteria, viz. effectiveness, efficiency, quality, productivity, and profitability. The developed CSCPME methodology may be applicable for the performance measurement and evaluation of almost all the entities of a supply chain.

KEYWORDS: SCM, SCPM, Effectiveness, Efficiency, Quality, Productivity & Profitability

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Original Article

INTRODUCTION

SCM has become an integrated part of all the organization snow a day as they begin to appreciate the criticality of creating an integrated relationship with their supplier, customers, and other stakeholders. Managing the supply chain has become way of improving competitiveness by reducing uncertainty and enhancing customer service. [Thomas and Grifith 1996, Capacino 1997] defines SCM as the management of materials, products and information flows from source to user. Also, number of Researchers conceptualize SCM from the perspective of purchasing and supply functions or a set of decisions or activities of purchasing and supplier management [Tan, 2001], and from the perspective of logistics and transportation functions. The literature on SCM essentially deals with strategies and technologies for effectively managing a supply chain. In recent years, the SC performance measurement receives significant attention from researchers and practitioners. As the purpose of a performance measurement system or model is to guide and support management in the selection of an appropriate performance measurement methods and performance metrics, suitable to their SC in order to improve performance of the SC.

The issue of how to design a useful performance measurement system has received increasing attention during the last decade, and various authors have presented ideas about what an ideal measurement system might look like [Caplice and Sheffi, 1995]. [Bititci et al., 1997] defined SCPMS as the reporting process that gives feedback to employees on the outcome of actions. [Tangen et al., 2004] proposed that performance be defined as

the efficiency and effectiveness of action, which leads to the following definitions: (i). Performance measurement is defined as the process of quantifying the efficiency and effectiveness of action; (ii). A performance measure is defined as a metric used to quantify the efficiency and/or effectiveness of an action; and (iii). Performance Management System is defined as the set of metrics used to quantify the efficiency and effectiveness of an action. [Neely, 2005] defined Performance Measurement System (PMS) as a balanced and dynamic system that enables support of decision-making processes by gathering, elaborating and analyzing information. [Taticchi et al., 2010] further elaborated this definition by commenting on the concept of 'balance' and 'dynamicity'. 'Balance' refers to the need of using different measures and perspectives that tied together give a holistic view of the organization. The concept of 'dynamicity' refers instead to the need of developing a system that continuously monitors the internal and external context and reviews objectives and priorities. An effective performance measurement system provides.

- The basic to understand the system
- Influences behavior throughout the system
- Provides information regarding the results of system efforts to supply chain members and outside stakeholders.

In effect, performance measurement is the glue that holds the complex value-creating system together, directing strategic formulations as well as playing a major role in monitoring the implementation of that strategy. In addition, research findings suggest that measuring supply chain performance in and of itself leads to improvements in overall performance. Also, Performance measurement has an important role in setting future course of actions and objectives [Gunasekaran, 2004].

The scope of performance measurement ranges from how a comprehensive performance measurement system should be designed, to ideas about which measures should be used to maximize performance. The increasing competitive imperatives in cost, efficiency and customer responsiveness have urged manufacturers to pursue a strategic alliance with both upstream and downstream partners such as suppliers, customers and even a host of logistics service providers to exploit their capabilities and to create new value to end customers.

BACKGROUND FOR RESEARCH

Performance measurement describes the feedback or information on activities with respect to meeting customer expectations and strategic objectives. It reflects the need for improvement in areas with unsatisfactory performance. Thus, efficiency and quality can be enhanced.

Since the early 1980s, a number of generic performance measurement models and frameworks, i.e. not necessarily specific to supply chains, have been developed. Each of which has its respective benefits and limitations. However, the literature review indicates that only very few of them [Tangen, 2004,Kurien and Qureshi, 2011] are widely cited and referred. The activity based costing (ABC) approach was developed by [Kaplan and Bruns, 1987] in attempt to tie financial measures to operational performance. The Balanced Scorecard (BSC) approach was proposed by [Kaplan & Norton, 1992] as a framework and process for performance assessment and it was designed to complement traditional measures maintaining balances between short-term and long-term objectives, financial and non-financial measures, lagging and leading indicators, and internal and external performance perspectives [Bhagwat and Sharma, 2007]. According [Shafiee etal. 2014]vast studies have been recorded on supply chain efficiency evaluation via BSC approach.

[Stern et al., 1995] introduced economic value added (EVA) approach for estimating a company's return on capital or economic value added. [Ghalayini & Noble, 1996] suggest that the main strength of the performance pyramid is its attempt to integrate corporate objectives with operational performance indicators. [Beamon, 1999] identified three types of measures as necessary components in supply chain performance measurement systems, namely: Resources (R), Output (O) and Flexibility (F). [Medori & Steeple, (2000] developed and presented an integrated framework for auditing and enhancing performance measurement systems.

Interface-based Measurement Systems (IBMS) was primarily put forward by [Lambert & Pohlen, (2001] they proposed a framework in which performance of each stage is linked within the supply chain. The performance prism is a measurement framework developed by [Neely et. al., 2001] indicates that the performance should be measured across five distinct but linked perspectives defined as stakeholder satisfaction, strategies, processes, capabilities and stakeholder contributions.[Hausman, 2003] suggests that a supply chain needs to perform well on three key dimensions: Service, Assets and Speed.

SCOR model was created by the Supply Chain Council [Stephens, 2001; Huang et al., 2004; Lockamy & McCormack, 2004]. It is a framework for examining the supply chain in detail through defining and categorizing the processes that make up the chain, assigning metrics to such processes and reviewing comparable benchmarks (Agami et al., 2012). The SCOR model framework can be found in [Huang et al., 2004]. [Thunberg and Persson, 2013] evaluated construction material supplier and construction site performance according to the SCOR model. [Sellitto, 2015] present a SCOR-based model for performance measurement in supply chains and apply it in the context of Brazilian footwear industry. The model has two dimensions: SCOR processes (source, make, deliver and return) and performance standards adapted from original SCOR (cost, quality, delivery and flexibility).

Perspective-based Measurement Systems (PBMS) look at the supply chain in all possible perspectives and provides measures to evaluate each of them was developed by [Otto and Kotzab, 2003] who identified six main perspectives as follows: System Dynamics, Operations Research, Logistics, Marketing, Organization and Strategy. The authors presented six unique sets of metrics, one for each perspective, to measure performance of supply chains. An example of a PBMS is the Logistics Scoreboard [Lapide, 2000] in which recommended performance measures focus only on logistical aspects of the supply chain.

[Gunasekaran, 2004] developed Hierarchical-based Measurement Systems (HBMS) in which measures are classified as strategic, tactical or operational. Function-based Measurement Systems (FBMS) is one in which measures are combined to cover the different processes in a supply chain [Ramaa, 2009]. It was originally developed by [Christopher, (2005] to cover the detailed performance measures applicable at different linkages of the supply chain. Efficiency-based Measurement Systems (EBMS) are systems that measure the supply chain performance in terms of efficiency. Several approaches were developed in this context [Chan, 2003,Chen and Paulraj 2004,Charan, 2007, Sharma and Bhagwat2007, Ramaa, 2009].

[Liang, 2006] developed a new Data Envelopment Analysis (DEA) based approach to measure the supply chain efficiency when intermediate measures are built into the evaluation scheme. It aimed at correcting the inadequacies of the conventional DEA model when evaluating multi-member supply chain operations directly. [Wong & Wong, 2007] provided a framework to study supply chain performance by developing a Data Envelopment Analysis (DEA) model for the internal supply chain performance efficiency using case study applications.

In this paper, a new performance measurement and evaluation system is described. It is based on the principle that the supply chain consists of different levels, e.g. supplier, manufacturing, distributing, and consumers and it is a network of companies which influence each other. The complexity and the large network affect one another’s performance. In inter organizational systems such as supply chains timely and accurate assessment of overall system and individual system component performance is of paramount importance [Equbal & ohdar, 2015]. An important component in SC design and analysis is the establishment of appropriate performance measures. A performance measures, or a set of performance measures, is used to determine the performance of an existing system, or to compare competing alternative systems. With a single performance measure, evaluating the performance of any organizational SC may lead to poor performance. To overcome this, a multi criteria performance measurement framework for supply chain has been proposed, which includes five specific performance criteria viz., effectiveness, efficiency, quality, productivity and profitability. The usefulness of each of these performance criteria may be different for different organizational SC. For example productivity may be ideal performance criteria in a typical organizational system, where cost reduction may be the prime concern, and effectiveness may be ideal performance criteria in another organizational system. The importance of these performance criteria may be decided based on the organizational system. Therefore, the selection of performance measures or variables constituting these performance criteria is an important aspect in developing a comprehensive performance measurement and evaluation system.

PERFORMANCE MEASUEREMENT AND EVALUATION METHODOLOGY

The supply chain is not just a chain of one-to-one business entities, but rather a network of multiple business entities and complex relationships [Lambert and Cooper, 2000]. For most supply chains, it looks less likely a pipeline or linear chain than an uprooted tree, where the branches and roots are the extensive network of customers and suppliers. The complexity of a supply chain is shown in Figure 1.

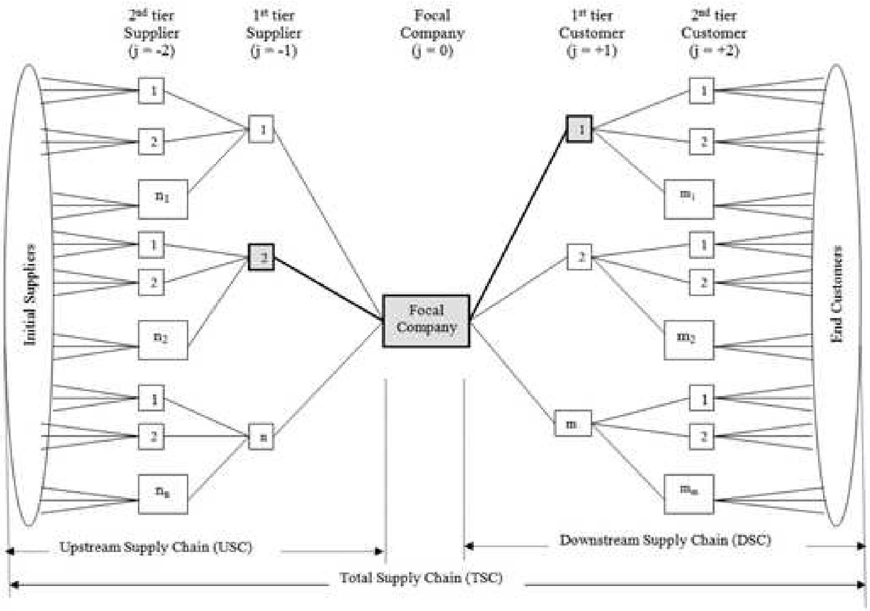

Figure 1: Supply Chain Network Structure

The focal company is placed in the center of the supply chain, whereas 1st tier, 2nd tier, and initial suppliers with a number of suppliers under each tier are placed in the upstream side of the supply chain, and 1st tier, 2nd tier and end

customers with a number of customers under each tier in the downstream side of the supply chain. Aiming to analyze and measure performance under the complex context, the research proposes a simplified supply chain model, which is based on three-entity and five process perspectives. In theory, any complex supply chain is the syntheses of these three basic components: supplier, manufacturer, and customer [Lochamy and Smith, 2000]. The three entities for supply chains respectively take one of the three processes: supplying, manufacturing, and customer ordering. Another two are inbound logistics and outbound logistics, which provides logistics services for the three basic entities. The inbound logistics includes purchasing, inbound transportation, and material warehousing, whereas, the outbound logistics concerns the functions of distribution, outbound transportation, finished products warehousing, and sales. The supply chain network is further divided as upstream supply chain (USC), focal company (FC), and downstream supply chain (DSC). The USC having a network of suppliers delivers the raw materials or semi-finished goods to the FC, whereas, on the other hand the DSC or the distribution channel provides the facility of distribution of the finished goods to the intermediate or immediate customers. The FC is the heart of any supply chain that takes almost all of the decisions for its supply chain. For the purpose of analyzing and measuring performance under the complex context, the structure of a simplified supply chain is shown in Figure 2.

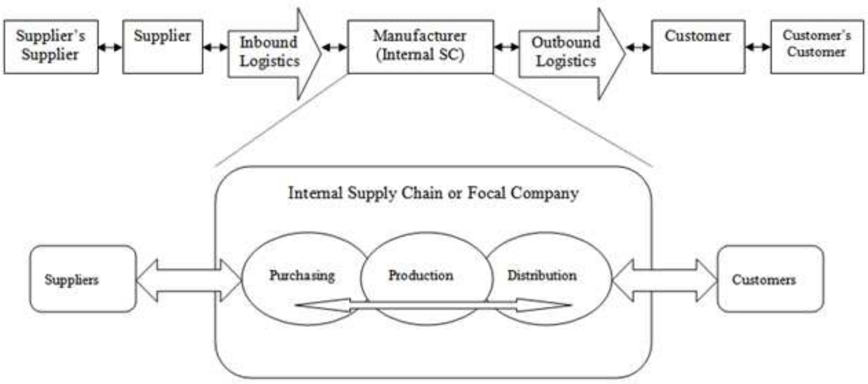

Figure 2: Structure of a Simplified Supply Chain Model

The modularized three-entity and five-process model widely covers the key components of supply chains. In SCM, a supplier of one supply chain can be the focal manufacturer or customer of another; at the same time, a customer of one supply chain may be the supplier of another. Just the multi-role nature of one organization in supply chains leads to the complexity of SCM, and also just the nature makes it possible to simplify supply chain network into the proposed model. A real supply chain system can be composed of more than one of this model in either horizontal or vertical direction. The model provides a new approach for analyzing, and measuring supply chain performance from a simplified system perspective. The proposed performance measurement system is just based on the simplified supply chain model.

Performance Measurement Hierarchy and Performance Measures

There is an increasing multitude of articles that address the design and implementation of performance measures for SC performance [Stewart, 1995].The general structure of the proposed supply chain performance measurement hierarchy (SCPMH) is shown in Figure 3. The supply chain is kept in the top level with a number of supply chain entities or companies in the second level of the hierarchy. Further for each supply chain entity/company, a number of corresponding performance criteria are identified and placed in the third level, and a number of associated performance measures under each performance criteria are placed in the fourth level of the hierarchy, thus building a supply chain

performance measurement hierarchy (SCPMH).

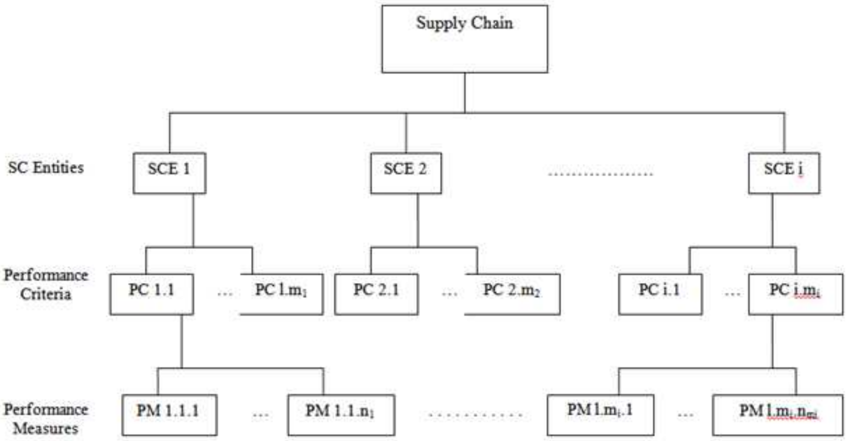

Figure 3: General Structure of the Supply Chain Performance Measurement Hierarchy (SCPMH)

In this section, the critical dimensions of performance measures are discussed from the following five specific performance criteria viz., effectiveness, efficiency, quality, productivity, and profitability.

In this model, the following notations are used:

i = Manufacturing or service plant (units), (i = 1, 2,........ n)

j = Manufacturing or service plant position (tier),

j = 0, [Focal Company]

j = +1, +2,........m1 [for downstream members of SC, viz. 1st tier, 2nd tier customers]

j = -1, -2,........... m2 [for upstream members of SC, viz. 1st tier, 2nd tier suppliers]

t = Study periods, (t = 1, 2,..........T)

Performance Measurement System for Supplir Link

Supplier link is the link between focal company and the upstream member i.e. suppliers. A number of performance measures have been identified, and grouped under three specific performance criteria viz. effectiveness, efficiency, and quality. In this link effectiveness, efficiency, and quality of incoming materials is monitored. For the uninterrupted supply of items to the successor entity in the supply chain, the role of supplier link is crucial, and to develop a performance measurement system for this link is very much required.

Effectiveness Measure (EM_{1t})

Effectiveness is an output or accomplishment issue. It is a measure of an organizational system’s performance which focuses on the output side of the system, it is defined as the level of accomplishment of functional values of products and services in fulfillment of the desired goals and objectives.

The effectiveness measures identified for supplier link are given below:

SDP_{ijt} = Supplier delivery performance of plant i, on tier j, in period t.

SPM_{ijt} = Supplier pricing against market of plant i, on tier j, in period t.

IDS_{ijt} = Inventory days of supply of plant i, on tier j, in period t.

$EM1_{ijt}$ = Total effectiveness performance of plant i, on tier j, in period t.

Assuming equal weightage to all the effectiveness measures,

$$EM1_{ijt} = \tfrac{1}{3}\left(SDP_{ijt} + SPM_{ijt} + IDS_{ijt}\right)$$

Efficiency Measures (EM_{2t})

Efficiency is an input-side or resource conversion measure that is concerned with the conversion rate of resources into products and services with the help of technology, methods and manpower available in a given period.

The efficiency measures identified for supplier link are given below.

SLT_{ijt} = Supplier lead time against industry norm for plant i, in tier j, in period t.

$POCT_{ijt}$ = Purchase order cycle time for plant i, on tier j, in period t.

$EM2_{ijt}$ = Total efficiency performance of plant i, on tier j, in period t.

Assuming equal weightage to all the effectiveness measures,

$$EM2_{ijt} = \tfrac{1}{2}\left(SLT_{ijt} + POCT_{ijt}\right)$$

Quality Measure (QM_t)

Quality is pervasive throughout the entire system. It is defined as the degree of conformation to specifications of activities of an organization system in relation to one or more of their desired values. It can be defined more operationally and in a way that facilitates measurement and that is consistent with the concept of the extended system. It refers to the quality of outputs or product produced or services rendered by an organization or supply chain entity.

The quality measures identified for supplier link are given below:

$ADFD_{ijt}$ = Achievement of defect free delivery of plant i, on tier j, in period t.

SBP_{ijt} = Supplier booking in procedure of plant i, on tier j, in period t.

QM_{ijt} = Total quality performance of plant i, on tier j, in period t.

Assuming equal weightage to all the quality measures,

$$QM_{ijt} = \tfrac{1}{2}\left(ADFD_{ijt} + SBP_{ijt}\right)$$

Performance Measurement System for the Focal Company

The Focal Company (refer to **Figure 1.**) is the heart of the supply chain. A number of upstream and downstream members are connected with the focal company. A number of performance measures are identified and grouped under the following five specific performance criteria: effectiveness, efficiency, quality, productivity, and profitability.

Effectiveness Measures

The effectiveness measures identified for the focal company are given below:

OFR_{ijt} = Order fill rate of plant i, on tier j, in period t.

OTD_{ijt} = On-time delivery of plant i, on tier j, in period t.

SF_{ijt} = Stock-out fraction of plant i, on tier j, in period t.

BF_{ijt} = Back-order fraction of plant i, on tier j, in period t.

$EM1_{ijt}$ = Total effectiveness performance of plant i, on tier j, in period t.

Assuming equal weightage to all the effectiveness measures,

$$EM1_{ijt} = \tfrac{1}{4}\left(OFR_{ijt} + OTD_{ijt} + SF_{ijt} + BF_{ijt}\right)$$

Efficiency Measures

The efficiency measures identified for the focal company are given below:

OCT_{ijt} = Order cycle time of plant i, on tier j, in period t.

MLT_{ijt} = Manufacturing lead time of plant i, on tier j, in period t.

CQT_{ijt} = Customers' query time of plant i, on tier j, in period t.

$POCT_{ijt}$ = Purchase order cycle time of plant i, on tier j, in period t.

DR_{ijt} = Delivery reliability of plant i, on tier j, in period t.

CU_{ijt} = Capacity utilization of plant i, on tier j, in period t.

$EM2_{ijt}$ = Total efficiency performance of plant i, on tier j, in period t.

Assuming equal weightage to all the efficiency measures,

$$EM2_{ijt} = \tfrac{1}{6}\left(OCT_{ijt} + MLT_{ijt} + CQT_{ijt} + POCT_{ijt} + DR_{ijt} + CU_{ijt}\right)$$

Quality Measures

The quality measures identified for the focal company are given below.

OCS_{ijt} = Overall customer satisfaction of plant i, on tier j, in period t.

MRR_{ijt} = Material rejection rate of plant i, on tier j, in period t.

ADF_{ijt} = Accuracy of demand forecasting of plant i, on tier j, in period t.

QM_{ijt} = Total quality performance of plant i, on tier j, in period t.

Assuming equal weightage to all the quality measures,

$$QM_{ijt} = \tfrac{1}{3}\left(OCS_{ijt} + MRR_{ijt} + ADF_{ijt}\right)$$

Productivity Measures

Productivity is the relationship between what comes out of the organizational system, in terms of quality products and services that satisfy human needs, and what goes into the organizational system, in terms of resources consumed to generate those products and services. It is, in a sense, the direct aggregation of all the previous performance measures, such as effectiveness, efficiency, and quality.

The productivity performance measures identified for the focal company are given below**:**

SR_{ijt} = Sales revenue of plant i, on tier j, in period t.

PC_{ijt} = Purchasing cost of plant i, on tier j, in period t.

MC_{ijt} = Manufacturing cost of plant i, on tier j, in period t.

DC_{ijt} = Distribution cost of plant i, on tier j, in period t.

ICC_{ijt} = Inventory carrying cost of plant i, on tier j, in period t.

$IfCC_{ijt}$ = Information carrying cost of plant i, on tier j, in period t.

I_{ijt} = Total input of plant i, on tier j, in period t.

O_{ijt}= Total output of plant i, on tier j, in period t.

Pd_{ijt} = Total productivity of plant i, on tier j, in period t.

Assuming equal weightage to all the input and output productivity measures,

$$I_{ijt} = \frac{1}{5}\left(PC_{ijt} + MC_{ijt} + DC_{ijt} + ICC_{ijt} + IfCC_{ijt}\right)$$

$$O_{ijt} = SR_{ijt}$$

$$Pd_{ijt} = \frac{O_{ijt}}{I_{ijt}} = \frac{SR_{ijt}}{\frac{1}{5}\left(PC_{ijt} + MC_{ijt} + DC_{ijt} + ICC_{ijt} + IfCC_{ijt}\right)}$$

Profitability Measures

Profitability measures the relationship between total revenue, and total costs. Financial measures are usually the primary measure of business success and there is no doubt that those organizations that are more productive tend also to be more profitable. Profitability is expressed in terms of several popular numbers that measure one of two generic types of performance: (i) how much they make with what they've got, and (ii) how much they make from what they take in.

The profitability measures identified for the focal company are given below:

PM_{ijt} = Profit margin of plant i, on tier j, in period t.

ROI_{ijt} = Return on investment of plant i, on tier j, in period t.

Pr_{ijt} = Total Profitability performance of plant i, on tier j, in period t.

Assume equal weightage to all profitability measures.

$$\mathrm{Pr}_{ijt} = \tfrac{1}{2}\left(PM_{ijt} + ROI_{ijt}\right)$$

Performance Measurement System for the Delivery Link

The delivery link is the link between focal company and the downstream members (customers) in the supply chain. The performance measures identified for this link are grouped under four specific performance criteria viz. effectiveness, efficiency, quality and productivity.

Effectiveness Measure (EM_{1t})

The effectiveness measures identified for delivery link are given below:

OTD_{ijt} = On-time delivery of goods of plant i, on tier j, in period t.

OFR_{ijt} = Order fill rate of plant i, on tier j, in period t.

TF_{ijt} = Transportation facilities of plant i, on tier j, in period t.

RUD_{ijt} = Response to urgent deliveries of plant i, on tier j, in period t.

Assuming equal weightage to all the effectiveness measures,

$EM1_{ijt}$ = Total effectiveness performance of plant i, on tier j, in period t.

$EM1_{ijt} = ¼ (OTD_{ijt} + OFR_{ijt} + TF_{ijt} + RUD_{ijt})$

Efficiency Measure (EM_{2t})

The efficiency measures identified for delivery link are given below.

DLT_{ijt} = Delivery lead time of the finished goods of plant i, on tier j, in period t.

CQT_{ijt} = Customer query time of plant i, on tier j, in period t.

$GRNT_{ijt}$ = Goods receipt note time of plant i, on tier j, in period t.

$EM2_{ijt}$ = Total efficiency performance of plant i, on tier j, in period t.

Assuming equal weightage to all the efficiency measures,

$EM2_{ijt} = 1/3\ (DLT_{ijt} + CQT_{ijt} + GRNT_{ijt})$

Quality Measure (QM_t)

The quality measures identified for the delivery link are given below:

NCC_{ijt} = Number of customer complaint of plant i, on tier j, in period t.

NFD_{ijt} = Number of faultless deliveries of plant i, on tier j, in period t.

QP_{ijt} = Quality of products of plant i, on tier j, in period t.

TE_{ijt} = Transportation error of plant i, on tier j, in period t.

QM_{ijt} = Total quality performance of plant i, on tier j, in period t.

Assuming equal weightage to all the quality measures,

QM_{ijt} = ¼ (NCC_{ijt} +NFD_{ijt} + QP_{ijt} + QM_{ijt})

Productivity Measure (Pd_t)

The productivity measures identified for the delivery link are given below.

QPD_{ijt} = Quantity of product delivery of plant i, on tier j, in period t.

TC_{ijt} = Transportation cost of plant i, on tier j, in period t.

LC_{ijt} = Labour cost of plant i, on tier j, in period t.

WC_{ijt}= Warehousing cost of plant i, on tier j, in period t.

OE_{ijt} = Other administrative related expenses utilized by plant i, on tier j, in period t.

I_{ijt} = Total input of plant i, on tier j, in period t.

O_{ijt}= Total output of plant i, on tier j, in period t.

Pd_{ijt} = Total productivity of plant i, on tier j, in period t.

Assuming equal weightage to all the input and output productivity measures,

I_{ijt} = ¼ (TC_{ijt}+ LC_{ijt} + WC_{ijt} + OE_{ijt})

O_{ijt} = QPD_{ijt}

$$Pd_{ijt} = \frac{O_{ijt}}{I_{ijt}} = \frac{QPD_{ijt}}{\frac{1}{4} \times (TC_{ijt} + LC_{ijt} + WC_{ijt} + OE_{ijt})}$$

Detailed flow chart for the existing performance measures under the mentioned categories for focal company, upstream members (suppliers) and downstream members (customers) are shown in **Figure 4**. The definitions of some of these performance measures are presented in **Appendix**.

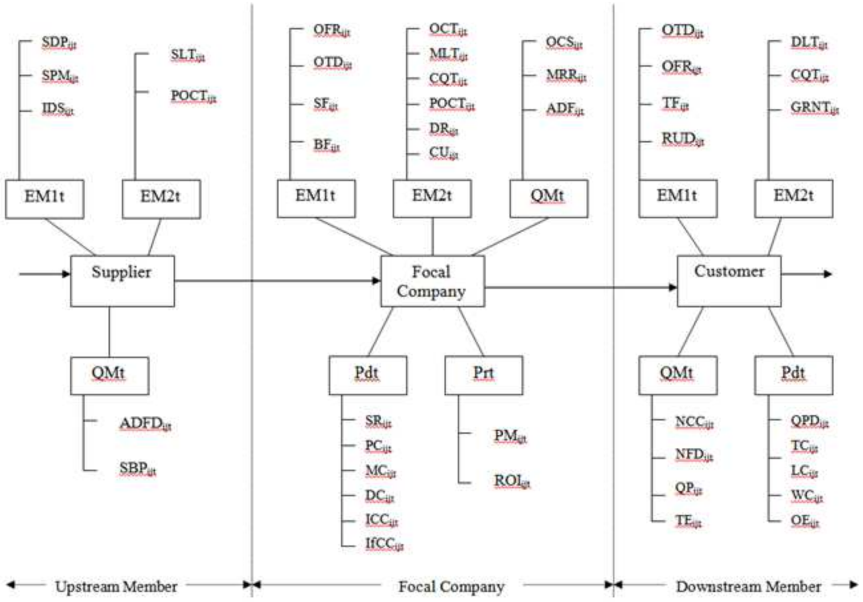

Figure 4: Flow Chart of Performance Measures for Supply Chain Performance Measurement and Evaluation System

CONCLUSIONS

The supply chain management is a concern for all industries now a day. A supply chain has to have particular advantages to customers. A good supply chain relies on its performance. Study reveals that the area of SCPM is growing in importance and scope. Both researchers and practitioners have been increasingly focusing on how to design and implement performance measurement systems for supply chains to cope with the continuous changes in their nature, context and requirements. In this paper, a comprehensive performance measurement and evaluation methodology for an integrated supply chain is proposed. A simplified supply chain model, which is based on three-entity and five process perspectives, is considered for analysis. The three entities for supply chain respectively take one of the three processes: supplying, manufacturing, and customer ordering. Remaining two are inbound logistics and outbound logistics providing logistics services for the three basic entities. The inbound logistics includes purchasing, inbound transportation, and material warehousing, the outbound logistics concerns the functions of distribution, outbound transportation, finished products warehousing, and sales. For the purpose of measuring and analyzing SC performance, the total supply chain is represented as an interplay between three sections, viz. upstream supply chain (USC), focal company (FC), and downstream supply chain (DSC). Five dimensional performance criteria are considered to analyze each section in the performance measurement system. An array of the five performance criteria viz. Effectiveness, Efficiency, Quality, Productivity and Profitability is defined for the measurement of supply chain performance.

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APPENDICES

Definitions of Supply Chain Performance Measures

- **Effectiveness Performance Measures**

- **Order Fill Rate (OFR)**: Order fill rate measures the magnitude or impact of stockouts over time. It is defined as the fraction of orders filled on due date. The OFR can be measured as

$$OFR\_(in\_\%) = 100 \times \left(1 - \frac{Number\_of\_SKU\_\sup plied\_late\_during\_time\_t}{Number\_of\_SKUs\_ordered\_during\_time\_t}\right)$$

- **On-time Delivery (OTD):** Number of shipment delivered on time: It is a product delivery performance measure. It can be represented by the percentage of orders delivered on or before the due date. The whole manufacturing process would be delayed significantly for any delay in delivery of materials. It is also known as delivery service level, and can be measured as

$$Delivery\_service\_level(\%) = 100 \times \left(1 - \frac{No\_of\_late\_shipment}{Total\_no.\_of\_shipments}\right)$$

- **Stockout Fraction (SF):** The stockout fraction is a customer service measure that computes the percentage of orders that result in a stockout at the customer level during a particular time period t. The stockout fraction is a measure of how well the supply chain is achieving customer service level objectives for end products. This quantity is given by:

$$SF = \frac{Number\_of\_SKU\_stockouts\_during\_time\_t}{Number\_of\_SKUs\_ordered\_during\_time\_t}$$

- **Backorder Fraction (BF):** The backorder fraction is also a customer service measure, calculating the proportion of backorders at the manufacturing facility and distribution centre during a particular time period t. The backorder fraction is a measure of how well the SC is achieving service level objectives for immediate materials and subassemblies. This quantity is given by:

$$BF = \frac{Number\_of\_SKU\_backordered\_during\_time\_t}{Number\_of\_SKUs\_ordered\_during\_time\_t}$$

- **Efficiency Performance Measures**

  - **Order Cycle Time (OCT):** The order cycle time, which is also called "order lead-time", refers to the time which elapses between the receipt of the customer's order and the delivery of the goods. This includes the following time elements:

Total order cycle time = Order entry time + Order planning time (Design + Planning + Scheduling time) + Order sourcing, assembly, and follow up time + Finished goods delivery time.

A reduction in the order cycle time leads to a reduction in the supply chain response time. This is an important measure as well as a major source of competitive advantage [Christopher, 1992]. According to Towill [1997], it directly influences the customer satisfaction level. The OCT may be measured as

$$Deviation\_in\_OCT(\%) = 100 \times \left(\frac{Norm\_(or\_average)\_OCT - Actual\_OCT}{Norm\_(or\_average)\_OCT}\right)$$

- **Manufacturing Lead Time (MLT)**: This is the elapsed time from transforming the raw material to finished goods. The MLT can be measured as

$$Deviation\_in\_MLT(\%) = 100 \times \left(\frac{Norm\_(or\_average)\_MLT - Actual\_MLT}{Norm\_(or\_average)\_MLT} \right)$$

- **Customer Query Time:** The customer query time refers to the time it takes for a firm to respond to a customer inquiry with the required information. On several occasions, a customer enquires or needs to be informed about the status of the order, and the potential problems on stock availability or delivery. Providing such information genuinely helps the customers to schedule their activities, and helps the firm to retain them as customers. Thus, providing online information is an important element of customer service, and it can be evaluated for improving the same.

- **Purchase Order Cycle Time (POCT): (**Or Supplier lead time against industry norm)the purchase order cycle time is the elapsed time from the customer placing an order to when the customer receives the order. One of the challenges for any company is to reduce the lead times.

$$Deviation\_in\_POCT(\%) = 100 \times \left(\frac{Norm\_(or\_average)\_POCT - Actual\_POCT}{Norm\_(or\_average)\_POCT} \right)$$

- **Delivery Reliability (DR)**: This is defined as the proportion of total orders delivered on time. It is a reflection not just of delivery performance but also of stock availability and order processing performance. It can be calculated as:

$$DR\_(in\_\%) = 100 \times \left(\frac{Number\_of\_orders\_delivered\_on\_time\_over\_a\_period\_t}{Total\_number\_of\_orders\_over\_a\_period\_t} \right)$$

- **Capacity Utilization**: All the operations planning takes place within the framework set by capacity decisions [Wild, 1995]. The role of "capacity" in determining the level of all supply chain activities is clear. This highlights the importance of measuring and controlling the capacity utilization. According to Slack et al. [1995], capacity utilization directly affects the speed of response to customers' demand.

- **Quality Performance Measures**

  - **Overall Customer Satisfaction (OCS)**: It can be measured by the number of customer complaints registered over a period t. It can be measured by

$$OCS\_(in\_\%) = 100 \times \left(1 - \frac{Number\_of\_customer\_complaint\_over\_time\_t}{Total\_number\_of\_order\_over\_time\_t} \right)$$

  - **The Material Rejection Rate (MRR)**: The material rejection rate can be measured as

$$MRR\_(in\_\%) = 100 \times \left(\frac{Quantity\_rejected\_in\_period\_t}{Quantity\_processed\_in\_period\_t} \right)$$

- **Accuracy of Demand Forecasting (ADF)**: The ADF is measured as a percent deviation of the actual demand from the forecasted demand.

$$ADF\_(in\_\%) = 100 \times \left(1 - \frac{Actual\_Demand\_over\_a\_period\_t}{Forecasted\_demand\_over\_a - period\_t} \right)$$

- **Productivity Performance Measures**
  - **Sales Revenue (SR)** over a period t: Sales revenue is the total amount of money that the company has earned from the sale of all its goods and services during a given time period. If a company produces just one product or service the sales revenue will be the price of the product multiplied by the number of the product sold. In the case of more than one product or service the revenue from each needs to be added together.
  - **Purchasing Cost (PC)** as a % of SR over a period t: The purchasing cost (PC) as a percentage of SR over a period t will be calculated as:

$$PC\_(in\_\%) = 100 \times \frac{Purchasing\_Cost}{Sales\_Revenue}$$

  - **Manufacturing Cost (MC**) as a % of SR over a period t: The Manufacturing cost (MC) as a percentage of SR over a period t will be calculated as:

$$MC\_(in\_\%) = 100 \times \frac{Manufacturing\_Cost}{Sales\_Revenue}$$

  - **Distribution Cost (DC**) as a % of SR over a period t: The distribution cost (DC) as a percentage of SR over a period t will be calculated as:

$$DC\_(in\_\%) = 100 \times \frac{Distribution\_Cost}{Sales\_Revenue}$$

  - **Inventory Carrying Cost (ICC)** as a % of SR over a period t: The Inventory carrying cost (ICC) as a percentage of SR over a period t will be calculated as:

$$ICC\_(in\_\%) = 100 \times \frac{Inventory\_Carrying\_Cost}{Sales\_Revenue}$$

  - **Information Carrying Cost (IfCC)** as a % of SR over a period t: The information carrying cost (IfCC) as a percentage of SR over a period t will be calculated as

$$IfCC\_(in\_\%) = 100 \times \frac{Information\_Carrying\_Cost}{Sales\_Revenue}$$

- **Profitability Performance Measures**
    - **Profit Margin (% of total sales revenue):** the net profit is the revenue less cost. It can be calculated as;

$$\Pr ofit\_M\arg in\_(in\%) = \frac{Net\_\Pr ofit}{Sales\_\mathrm{Re}venue} \times 100$$

    - **Return on Investment (ROI)** [Christopher, 1992]: Return on investment is the ratio between the net profit and the capital that is employed to produce that profit, thus:

$$ROI = \frac{\Pr ofit}{Capital\_employed}$$

This ratio can be further expanded

$$ROI = \frac{\Pr ofit}{Sales} \times \frac{Sales}{Capital\_employed}$$

It is defined that ROI is the product of two ratios: the first being commonly referred to as the margin and the second, termed as capital turnover.